14.2 Summary of the Ecological Risk Assessment

All of the ecological risk assessment activities at the Site were performed under the EPA's 8 step process and guidance titled "Ecological Risk Assessment Guidance for Superfund: Process for Defining and Conducting Ecological Risk Assessments" (ERAGS, EPA 1997, and with the submittal of the Final Baseline Ecological Risk Assessment (BERA), all 8 steps have been completed. The first phase in the ecological risk process, the Screening-Level Ecological Risk Assessment (SLERA, PBW 2010a), concluded that there were no upper trophic level risk to ecological receptors consuming food or soil, sediment, and surface water media containing site-related contaminants of potential ecological concern (COPECs). However, the Scientific/Management Decision Point (SMDP) provided in the Final SLERA concluded that a potential was indicated for adverse toxicological ecological effects to soil- and sediment-dwelling invertebrates for COPECs (PAHs, metals, and pesticides). Thus, a more thorough Baseline Ecological Risk Assessment (BERA, URS 2011) was warranted, and subsequently conducted.

The BERA Work Plan & Sampling and Analysis Plan (SAP) and BERA Problem Formulation were submitted to the EPA on June 22, 2010 and approved with modifications by the EPA on August 4, 2010. Following acceptance of the Final BERA Work Plan and SAP, sample collection, laboratory analysis, and data validation were conducted. The BERA 60 day deliverable, which was submitted to the EPA on October 4, 2010, summarized the field activities, toxicity testing, chemical analyses and data validation. Following EPA approval of the Preliminary Site Characterization Report (PSCR), the draft BERA Report was submitted to EPA within sixty (60) days.

The BERA Work Plan and SAP described a study to assess site-specific toxicity to invertebrates to COPECs in the North Area soils, wetland sediments, Intracoastal Waterway sediments, and surface water from the wetland area. Toxicity testing of sediment was conducted using the 28-day whole-sediment tests for the polychaete *Neanthes arenaceodentata a*nd the amphipod *Leptocheirus plumulosus* using the wetland sediments and Intracoastal Waterway sediments. A 21-day whole sediment/soil toxicity test using *Neanthes arenaceodentata* was applied to the North Area soils. The bioassays for the surface water were conducted on brine shrimp (*Artemia salina*) and assessed at a 48-hour duration. All of the BERA sediment and soil sample locations were chosen based on a concentration gradient of the chemicals of potential ecological concern (COPECs) identified in the SLERA.

The objective of the BERA Report is to characterize the Site-specific risks using samples of surface soil, surface sediment, and surface water in accordance with the study design identified in the Final BERA Work Plan and SAP.

The evaluation of toxicity and analytical data showed that the most relevant comparison was between Site and reference sample locations. This approach allows for a comparison of locations that exhibit similar environmental conditions, except for the presence of Site-related COPECs. Ultimately, it was determined that there is no statistically significant difference in the toxicity observed in samples collected at the reference locations and the Site for sediment/soil exposure and that there was no toxicity associated with the surface water locations. Because of the lack of evidence of Site-related toxicity, development of ecologically-based remediation goals is not necessary.

14.2.1 Screening Level Ecological Risk Assessment (Steps 1 and 2)

The purpose and scope of the SLERA was to summarize the analytical data for environmental media sampled during the RI and to complete Steps 1 and 2 of the EPA's Ecological Risk Assessment process based on those data. The SLERA was a conservative assessment and served to evaluate the need and, if required, the level of effort necessary to conduct a BERA. Per the EPA guidance (1997), a SLERA is to provide a general indication of the potential for ecological risk (or lack thereof), and was conducted for several purposes including: 1) to estimate the likelihood that a particular ecological risk exists; 2) to identify the need for site-specific data collection efforts; or 3) to focus site-specific ecological risk assessments where warranted.

The SLERA (PBW, 2010a) compared maximum concentrations of the COPECs to protective ecological benchmarks for direct contact toxicity. The SLERA concluded that there may be the potential for adverse impacts to sedentary biota communities in surface soil from several COPECs that exceeded a Hazard Quotient (HQ) of 1 in the South Area and North Area. A Hazard Quotient is obtained by dividing each ecological receptor's exposure to each COPEC concentration by the protective toxicity effects criterion for each COPEC. In addition, the SLERA indicated a potential for localized adverse ecological effects to sedentary biota communities in sediment. Concentrations of the COPECs that exceeded the midpoint of the toxicity effects range–low and effects range-median (ERL and ERM) concentration levels in sediment of the North Area wetlands, Intracoastal Waterway and the Ponds were predicted to have toxic effects. The SLERA also concluded that there was a possible risk from direct toxicity to aquatic species, including fish (due to acrolein and dissolved copper in the surface water of the North Area wetlands, and silver in the surface water of the Ponds and the Background Intracoastal Waterway area).

It should be noted that the SLERA determined that adverse effects resulting from soil ingestion, sediment ingestion, surface water and/or food chain exposures to higher trophic-level receptors were unlikely or insignificant because HQs for higher trophic-level receptors were less than 1.

14.2.2 Baseline Ecological Risk Assessment Problem Formulation (Step 3)

Following completion of the SLERA, the BERA Problem Formulation was conducted to identify the specific ecological issues at the Site and determine the scope and goals of the BERA. The BERA Problem Formulation further refined or identified the COPECs, characterized ecological effects of the COPECs, reviewed fate and transport, complete exposure pathways, and potential ecosystems at risk, determined assessment endpoints (specific ecological values to be protected), and developed a conceptual site model with ecological risk questions to be addressed.

Steps were taken to refine the COPEC list (i.e., modification of conservative exposure assumptions and review of spatial COPEC distributions) and conduct a literature research to further characterize ecological effects of the refined list of COPECs, as well as to review their fate and transport characteristics relative to Site conditions. Subsequent to these steps, the following ecosystems were identified as potentially at risk for the following COPECs:

- Wetland sediments and surface water: The primary COPECs with HQs greater than 1 in wetland sediment were several polycyclic aromatic hydrocarbons (PAHs). Most of the HQ exceedances for the PAHs were located in three areas: (1) a small area immediately northeast of the capped surface impoundments; (2) a smaller area immediately south of the capped surface impoundments; and (3) at a sample location in the southwest part of the North Area approximately 60 feet north of Marlin Avenue. Other COPECs included the organochlorine pesticides and metabolites (4,4'-DDT, endrin aldehyde, and endrin ketone). The metals that were COPECs included arsenic, copper, lead, nickel, and zinc. Additionally, total acrolein and dissolved copper were surface water COPECs in the wetland area northeast of the capped surface impoundments. The COPECs in the Small Pond included 4,4'-DDT and zinc in the sediments and silver in the surface water.

- Intracoastal Waterway sediment within former Site barge slips: The predominant COPECs in these areas, as reflected by HQ exceedances, were PAHs. The total PAH concentration was highest in the northernmost sample in the western barge slip. In the eastern barge slip, the COPECs were three PAHs, hexachlorobenzene, and the sum of high molecular-weight PAHs (HPAHs). The only organochlorine pesticide COPEC was 4,4'-DDT.

- North Area soils south of the capped surface impoundments: The metals COPECs in this area, where some buried debris was encountered in the shallow subsurface, were barium, chromium, copper, and zinc. Organic COPECs included 4,4'-DDT and Aroclor-1254.

The risk questions developed through the BERA Problem Formulation were:

1. Intracoastal Waterway and Wetlands sediments: Does exposure to COPECs in sediment adversely affect the abundance, diversity,

productivity, and function of sediment invertebrates as an aquatic community?

2. Wetlands and Pond surface water: Does exposure to COPECs in surface water adversely affect the abundance, diversity, productivity, and function of water-column invertebrates and fish?

3. North Area soils: Does exposure to COPECs in soil adversely affect the abundance, diversity, productivity, and function of soil invertebrates as a terrestrial community?

Justification for removal of the South Area from the ecological risk process was provided in the approved Final BERA Problem Formulation Report (URS 2011) for the following habitat-related considerations:

1. It is zoned by the City of Freeport as “W-3, Waterfront Heavy”, which provides for commercial and industrial land use, primarily port, harbor, or marine-related activities;

2. A restrictive covenant placed on the deed ensures that future land use for this parcel of land is commercial/industrial;

3. The area does not serve as valuable habitat, foraging area, or refuge for ecological communities, including threatened/endangered or otherwise protected species;

4. The area does not contain consistent and contiguous habitat but, rather, the area is broken up by the presence of concrete slabs, pads, driveways, and areas of compacted shell;

5. The area exhibits minimal ecological functions because of the disturbed nature of the land and historical industrial use of the property and adjacent properties; and

6. There are minimal, if any, attractive features at the South Area that would support a resident wildlife community.

Since the Site was developed in the early 1960s, it has been used for industrial purposes. It is also bounded by former and/or current industrial properties to the east and west. The Site has not been used since approximately 1999 and opportunistic grasses and small shrubs have grown on some portions of the South Area that do not have concrete, oyster shell, or gravel cover. The South Area will be used in the future for commercial/industrial purposes since the barge slips are valuable to many types of businesses in the area, and it is unlikely that the Site will return to “natural” conditions. The evidence indicates that the South Area soils do not represent a valuable ecological resource that warranted further evaluation in order to protect invertebrates such as earthworms and, therefore, there was no further assessment of the South Area soils (URS, 2011).

14.2.3 BERA Work Plan – Study Design and Data Quality Objectives (Step 4)

The BERA Work Plan was prepared to describe the investigation components necessary to complete the BERA. The Work Plan included a Sampling and Analysis Plan (SAP) that established the specific sampling locations, equipment, and procedures to be used during the BERA. The BERA Work Plan & SAP was finalized on September 2, 2010.

The overall objective to be addressed by the BERA is to evaluate the specific contaminants, pathways, and receptors identified in the SLERA as warranting additional investigation. Data Quality Objectives (DQOs) were established for the BERA through the Problem Formulation steps to identify the assessment endpoints and risk questions (Table 1 – Assessment Endpoints and Measures). The DQOs were based on the proposed end uses of data generated from sampling and analytical activities. The DQOs are qualitative and quantitative statements that outline the decision-making process and specify the required data.

14.2.3.1 BERA Exposure Analysis

To address the BERA objectives and risk questions listed in the Problem Formulation (URS, 2010b), an investigation program was developed that used multiple lines of evidence including sediment toxicity testing, surface water toxicity testing, measures of COPEC bioavailability, and COPEC concentration data.

The investigation program included bioassays of invertebrates coupled with chemical analyses of soil, sediment, pore-water, and surface water. The bioassays, chemical analyses, and determination of COPEC bioavailability represent three lines of evidence that were used to support the conclusions of the BERA. The analyses were selected to incorporate the media, pathways, and COPECs relevant to the assessment endpoints (Table 1 – Assessment Endpoints and Measures). Sampling, analysis, and data evaluation protocols were selected to ensure that the data collected are scientifically defensible and applicable to the BERA objectives. Sample station locations were selected based on COPEC concentrations along a gradient. Sampling locations are provided on Figures 3 (North Area Soil Sample Locations), 4, (Wetland Sediment Sample Locations), 5 (Intracoastal Waterway Sediment Sample Locations), 6 (Intracoastal Waterway Reference Sediment Sample Locations), and 7 (Wetland Surface Water Sample Locations).

14.2.4 Field Verification of Sampling Design (Step 5)

The purpose of the Field Verification of the Sampling Design (Step 5) is to evaluate the appropriateness and implementability of the testable hypotheses, exposure pathway model, and measurement endpoints created in Steps 3 and 4 (EPA 1997). There were two significant adjustments to the toxicity testing protocol: 1) the test species for the North Area soil was changed from the earthworm (*Eisenia fetida*) to the polycheate *Neanthes arenaceodentata* and the soils were treated as sediments in the toxicity testing and 2) the surface water test species was changed from Mysid shrimp (*Mysidopsis bahia*) to brine shrimp (*Artemia*). Both of these adjustments were due to the elevated salinity commonly found in the salt panne environment and were discussed and approved by EPA prior to completing the study.

14.2.5 Site Investigation and Data Analysis Phase (Step 6)

Field activities and laboratory testing were conducted in August and September 2010 to support the BERA. Sample collection methods, the pore-water extraction method, field measurements procedures, laboratory analytical methods, toxicity testing methods, and data validation procedures were specified in the Field Sampling Plan (FSP), Quality Assurance Project Plan (QAPP) and/or Final BERA Work Plan & SAP. BERA field activities were also conducted in accordance with the Site-specific Health and Safety Plan.

14.2.6 Environmental Media Sampling

The initial environmental media sampling to support the BERA began on August 12, 2010 and was completed on August 31, 2010. Samples were analyzed for those COPECs listed in the Final BERA Work Plan & SAP. Total organic carbon (TOC) data were obtained for the sediment samples from the wetlands area and the Intracoastal Waterway. Simultaneously-extracted metals, acid volatile sulfides (SEM/AVS) and grain size analysis were obtained for the wetland sediments. Data gathered in the field such as water depth, pH, conductivity, temperature, salinity and dissolved oxygen for water and pH, oxygen reduction potential and temperature are shown on Tables 2 (Field Sampling Parameters – Water) and 3 (Field Sampling Parameters – Sediment).

The pore water sample EWSED04PW collected on August 27, 2010 could not be analyzed for PAHs due to a laboratory error. Field activities were re-initiated on September 9, 2010 to collect the pore water sample from the same location. While the sampling team was present on the Site, they evaluated whether sufficient pore water was present at EWSED03, EWSED05, and EWSED09 (as well as sufficient surface water from EWSW02 and EWSW03) that had previously been dry. All of these pore water and surface water samples, except for EWSED05PW and EWSW02, were subsequently collected in September 2010.

Consistent with the BERA Work Plan & SAP, there were no analytical samples formally archived for this project.

14.2.7 Toxicity Testing Protocols

Toxicity testing of sediment was conducted using the 28-day whole-sediment tests for the polychaete *Neanthes arenaceodentata* and *Leptocheirus plumulosus* using the wetland sediments and Intracoastal Waterway sediments as described in the Final BERA Work Plan & SAP. The sediment toxicity testing was conducted from August 25 through September 22, 2010.

Responses of test organisms exposed to laboratory control samples for all of the sediment toxicity tests indicated that the test organisms were of acceptable health. Additionally, the reference and Site toxicant tests were within acceptable quality control parameters. The purpose of the laboratory control tests is to determine the validity of the test. The sediment used for the laboratory controls is taken from the York River in Virginia, processed to remove vegetative matter, and then frozen to remove live indigenous organisms that could prey upon the test species. The effect of freezing the sediments on the health of the test organisms is unknown, although it likely imparts little uncertainty in the analysis since it is commonly performed and follows standard procedures.

Conducting the 28-day earthworm (*Eisenia fetida*) bioassays for North Area soils, as proposed in the Final BERA Work Plan & SAP was problematic given significantly elevated salinity levels in the six (6) Site and three (3) reference soil sample locations. When the earthworms were introduced to the North Area soil samples in the laboratory, there was an immediate avoidance reaction followed by acute mortality in all of the Site and reference location samples. The elevated salinity levels are believed to be due to frequent inundation with estuarine water related to storm events. Also, much of the soil/sediment in the North Area uplands was originally dredge spoils from the Intracoastal Waterway used as fill material. Following discussion and agreement by the EPA on September 3, 2010, an alternative method for the earthworm bioassays was developed. The nine (9) soil samples from this transitional area were treated as sediment by adding synthetic seawater, and the polychaete *Neanthes arenaceodentata* was exposed over a 21-day test duration with growth and survival endpoints. According to the National Oceanic and Atmospheric Administration (NOAA), survival and growth endpoints "are about equal sensitivity" for *Neanthes arenaceodentata* (MacDonald et al., 2003). Polychaetes are more phylogenetically and taxonomically similar to earthworms than amphipods, such as *Leptocheirus plumulosus*, and are members of the “sediment-ingesting invertebrate” feeding guild that the earthworm was chosen to represent. The 21-day test duration is conservative given the ephemeral nature of the inundation events at the Site. The North Area soil toxicity testing was conducted from September 10 through October 1, 2010.

Similar to the North Area soils, elevated salinity levels measured in August 2010 were also a concern for surface water samples EWSW01 and EWSW04. As-received salinities of 40‰ and 39‰, respectively, were measured by PBS&J Environmental Toxicology Laboratory, and would likely result in significant stress to the mysid shrimp

(*Mysidopsis bahia*) proposed in the Final BERA Work Plan & SAP. As previously discussed, these elevated salinity levels are indicative of a salt panne. Therefore, the bioassays for the surface water were conducted on brine shrimp (*Artemia salina*) that are better suited for high salinities. There are no standard laboratory methods for testing chronic exposures to brine shrimp. Therefore, PBS&J Environmental Toxicology Laboratory developed a standard operating procedure (SOP) for conducting acute tests with a survival endpoint by referencing standard procedures for determining toxicity from produced (oilfield) waters (SPE, 1978). This shortened test protocol, from 7 days to 48 hours, is more representative of the ephemeral nature of surface water in the areas being evaluated and was demonstrated with the toxicity testing to be more reliable (as described in more detail in the following paragraph). Use of the alternative species and test protocol was approved by the EPA on September 3, 2010 at a test duration of 48 hours.

The surface water toxicity tests with *Artemia* were conducted three times between September 16 and October 3, 2010. The initial test was potentially affected by a laboratory technician using an incorrect food for the test organisms; however the lab control showed 100% survival at 48 hours. The second test exhibited excessive control mortality (failure) (i.e., less than 90% survival of the control) after 48 hours, and the third test was completed with excessive control mortality (failure) after 96 hours but acceptable lab control survival at 48 hours (90%). The applicability of the 96 hour test duration is questionable. On December 1, 2010, a meeting was held with Texas Commission on Environmental Quality (TCEQ) and EPA where it was decided that the original test duration of 96 hours was not acceptable for this test species and site conditions, and that the test duration of 48 hours, as described in the original standard procedure (SPE, 1978), would be the accepted test duration.

For the evaluation of the toxicity of Site sediment and soil samples, the most relevant comparison is to results for reference location samples. This enables the comparison of results between Site samples and reference samples that exhibit similar environmental conditions, but are not influenced by releases from the Site. It should be noted that reference samples may contain background concentrations of one or more naturally occurring metals as well as anthropogenic constituents that are not related to Site activities (EPA, 2002).

14.2.8 Results of Chemical Analyses and Toxicity Testing

Chemistry data generated from the BERA sampling and analyses were compared to the previously-collected data to evaluate the COPEC concentration gradients across the Site. The 2010 BERA data were also compared to the applicable screening benchmarks as listed in the BERA Work Plan and SAP (Table 6 – Summary of Results for Wetland Sediment). TCEQ (2006) is the primary source for the screening benchmarks. Site investigation activities are described by environmental medium and/or area in the sections below. The following text provides a discussion of the COPEC gradients, screening level and/or reference location concentration (not Site related) exceedances, and corresponding toxicity testing results with supporting tables and figures. The statistical analysis of the toxicity test results is discussed by study area. Table 4 (Summary of Toxicity Testing for Soil and Sediment) is a summary of the toxicity testing results for each of the study areas without statistical comparison of the Site samples with reference samples; however, note that the mean growth and mean survival toxicity results are based on multiple replicates of the test chambers per sample. Thus, results presented on Tables 4, 5, 6 and 9 and throughout the BERA, should be considered as a mean calculation of the replicates and not a single test result. The determination of the statistical comparison is based on the methods outlined in the BERA Work Plan and SAP which describes that significant differences for the toxicity tests set at $P< 0.05$. Discussion of the statistical and biological significance of the data is presented in the following sections.

14.2.8.1 North Area Soil

There were 6 Site and 3 reference samples collected. Soil sample depth was 0 to 0.5-foot. The COPECs for the North Area soil are 4,4'-DDT, Arochlor-1254, barium, chromium, copper, and zinc.

14.2.8.1.1 Ecological Setting

The North Area soils represent areas that are topographically higher than the wetland sediments, and are subject to flooding from extreme rainfall or storm surges. Therefore, the area does not represent an upland terrestrial area, but more of a transitional area between wetland sediments and soils. The dominant crustacean in such a transitional area is typically the fiddler crab (Uca spp.). Fiddler crabs were noted by the field crew to be present during sample collection. They are detritivores that feed near their burrows during low tide by separating organic detritus from sediment using specialized legs (Barnwell, 1968). The burrowing crabs, the marsh crab (*Sesarma cinereum*) and the land crab (*Cardisoma guanhumi*) are also typical of high marsh environments. The primary food source for the marsh crab is *Spartina* detritus, but it will eat small fiddler crabs when they are available (Seiple, 1979). The land crab is an omnivorous scavenger. Both species are eaten by mammalian predators, such as raccoons and coyotes. Other crustaceans often present in the transitional area are hermit crabs (*Clibanarius vittatus* and *Pagurus longicarpus*) (Young, 1978). Hermit crabs move frequently between the intertidal marsh and the high marsh and are omnivorous scavengers that seek out animal tissues and other organic detritus.

14.2.8.1.2 Analytical Chemistry Results

In general, the 2010 BERA analytical results for North Area soils are lower than the analytical results from the RI data collected in 2009. Table 5 (Summary of Results for North Area Soil), for Site and reference sample locations, shows the BERA data with exceedances of the benchmarks for barium, chromium, copper and zinc. The COPECs 4,4'-DDT and Aroclor-1254 are the only two organic COPECs with exceedances of marine sediment benchmarks (Table 5), which are the ERL conservative screening criteria (Long et al., 1995). A concentration gradient for the two (2) organic COPECs was not apparent from the 2010 data, but is apparent for the inorganic COPECs (see Table 5).

14.2.8.1.3 Toxicity Results

The results from the North Area soils toxicity tests showed no statistically significant differences in toxicity results using the test species *Neanthes arenaceodentata* in site samples when compared to the reference locations. As shown on Tables 4 (Summary of Toxicity Testing for Soil and Sediment) and 5 (Summary of Results for North Area Soil), mean survival rates ranged from 76% to 96% in the North Area soil samples. The toxicity results did not consistently correlate with the results of the analytical chemistry.

14.2.8.2 Wetland Sediment

There were 7 Site and 2 reference area samples collected, as shown on Figure 4 (Ground Water Investigation Locations). Sediment samples depths were 0 to 0.5-foot. Sediment pore water was extracted and analyzed for COPECs for all (but one sediment sample, EWSED05, which was too dry to extract pore water). There was not a formal assessment of benthic invertebrates in the samples during the field event; however, polychaete worms and fiddler crabs were observed in all of the wetland sediment sample locations, including the reference locations. The COPECs for the wetland bulk sediment and pore-water include 2-methylnaphthalene, 4,4’-DDT, acenaphthene, acenaphthylene, anthracene, arsenic, benzo(a)anthracene, benzo(a)pyene, benzo(g,h,i)perylene, chrysene, copper, dibenz(a,h)anthracene, endrin aldehyde, endrin ketone, fluoranthene, fluorene, gamma-chlordane, indeno (1,2,3-cd)pyrene, lead, nickel, phenanthrene, pyrene, and zinc.

14.2.8.2.1 Ecological Setting

The wetland sediment area can be considered a salt panne. In general, the intertidal zone receives nutrients flushed from the supra-tidal zone and nutrients that are filtered out of near-shore waters; however the area is hyper-saline, and conditions are considered harsh. Similar to the North Area soil, the dominant crustacean in this area is the fiddler crab (*Uca* spp.). Juvenile blue crabs, which may also be present, take refuge in the marsh areas, but migrate to the subtidal zone as they get larger. Mud crabs (*Neopanope texana* and *Panopeus herbstii*) typically live in shallow mud or under shoreline debris and feed on oyster spat, barnacles, snails and smaller crabs (Reames and Williams, 1983). Other crustaceans that may live in the area are hermit crabs (*Clibanarius vittatus* and *Pagurus longicarpus*) (Young, 1978), and mud shrimp (*Callianassa jamaicense*). All are omnivorous scavengers that feed on organic detritus trapped in marsh sediment (Fotheringham, 1975).

14.2.8.2.2 Analytical Chemistry Results

In general, the 2010 BERA analytical results for wetland sediments were lower than the analytical results from the RI data collected in 2008. Table 6 (Summary of

Results for Wetland Sediment) shows exceedances of the sediment benchmarks for several individual PAHs and metals (lead, nickel and zinc) in the BERA samples. The only exceedances of surface water benchmarks from Site wetland sediment pore-w,ter were for endrin aldehyde, endrin ketone, copper, and zinc. The only exceedances of either sediment or surface water benchmarks in the reference samples were 4,4'-DDT in sediment, and 4,4'-DDT, endrin aldehyde, and nickel in sediment pore water. As shown on Table 6, concentration gradients were identified for the majority of the COPECs.

Detailed information on sediment grain size and SEM/AVS analytical results are presented on Table 7 (Summary of Grain Size Data for Wetland Sediment) and Table 8 (Summary of AVS, SEM and Organic Carbon-Normalized Excess SEM Data for Wetland Sediment), respectively. The SEM/AVS ratios presented in Table 8 are all above 1.0, (except for EWSED08, with an SEM/AVS ratio of 0.157), which indicates that the potential exists for metal toxicity since sufficient AVS to completely form insoluble metal sulfides is not present. However, sediment organic carbon can also bind the free metals and reduce their availability to aquatic organisms. The ratio of "excess" SEM to the fraction organic carbon content of sediment was below 130 micromoles per gram organic carbon ($\mu mol/g_{oc}$), the concentration predicted to be non-toxic by the EPA (2005), for six (6) of seven (7) Site samples. Also, the remaining Site sample (EWSED06) had an organic carbon-normalized excess SEM ratio of 168, which is at the low end of the range where the prediction of toxicity is uncertain (130 to 3,000 $\mu mol/g_{oc}$; EPA, 2005). The sediment grain size data presented in Table 7 are fairly consistent between locations, except for the relatively high fraction of gravel and low fraction of clay found at EWSED02 and EWSED03, as compared to the opposite situation (low fraction of gravel and high fraction of clay) at EWSED01, EWSED04, EWSED06, EWSED07, and EWSED09.

14.2.8.2.3 Toxicity Results

Tables 4 (Summary of Toxicity Testing for Soil and Sediment) and 6 (Summary of Results for Wetland Sediment) include a summary of the wetland sediment toxicity testing (bioassay) results. For the polychaete, *Neanthes arenaceodentata* and the amphipod, *Leptocheirus plumulosus*, there were no statistically significant differences between the seven (7) Site samples and the two (2) reference samples for the survival or growth endpoints. Insufficient offspring were produced for a statistical analysis of the reproduction endpoint for amphipods.

The results of the toxicity study did not consistently correlate well with the results of the analytical chemistry. These results serve to illustrate the fact that toxicity test organism responses reflect exposure to the full balance of potential stressors, not individual COPECs. These stressors include Site COPECs and other types of stressors (e.g., elevated salinities) that can exert independent and collective effects. Thus, caution should be exercised when interpreting such data regarding the co-occurrence of screening benchmarks.

14.2.8.3 Intracoastal Waterway Sediment

There were 5 Site and 2 reference area samples collected, as shown on Figures 5 (Potential Source Areas) and 6 (EM Survey Transects and Data), respectively. Sediment sample depth was 0 to 0.5-foot. There was not a formal assessment of benthic invertebrates in the samples during the field event; however, benthic invertebrates were observed in all of the Intracoastal Waterway sediment samples, including the reference samples. The most abundant organisms appeared to be polychaete worms (*Neanthes spp.*). Additionally, mud crabs and snapping shrimp were observed by the field crew in some of the sediment samples. Sediment pore water was extracted from all seven (7) locations and analyzed for Site COPECS. The COPECs for the Intracoastal Waterway bulk sediment and pore-water include 4,4'-DDT, acenaphthene, benzo(a)anthracene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, hexachlorobenzene, phenanthrene, and pyrene.

14.2.8.3.1 Ecological Setting

The benthic communities found in the Intracoastal Waterway and Oyster Creek in the Site vicinity are very similar to the communities that would be found in a primary or secondary bay on the Texas Gulf Coast. The Intracoastal Waterway represents a diverse ecological system. However, water depths, vehicle traffic, reduced light penetration, and higher than normal tidal energy prevent submerged vegetation from growing in the Intracoastal Waterway near the Site. The absence of attached vegetation that provides food and shelter decreases the number of invertebrate species that can utilize the habitat. Most of the epibenthic invertebrates that utilize the subtidal zone in the Intracoastal Waterway are migrants. In areas where tidal energy is reduced, sediment and organic detritus can accumulate and create a habitat for benthic infauna (Heald, 1971). A summary of potential ecological receptors typically present in Texas bay systems is presented below. These species may or may not be present in the Intracoastal Waterway in the site vicinity.

The most common invertebrates in the subtidal zone are the micro- and macroinfauna. Microinfauna includes bacteria, flagellates, diatoms, and small worms and may represent a significant portion of the infaunal biomass. The macroinfauna (> 0.5 mm) include polychaete worms, copepods, gastropods, amphipods, and isopods. Parchment worms (*Chaetopterus variopedatus*) and lugworms (*Arenicola cristata*) are tube-dwelling polychaete worms that are common in the subtidal sediment. Other polychaete worms are *Eteone heteropoda*, *Laeonereis culveri*, *Neanthes succinea*, *Ceratonereis irritabilis*, and *Capitella capitata*. *E. heteropoda* and *C. capitata* are deposit feeders. The other polychaetes are active predators and feed on other invertebrates.

Bivalves and gastropods are also commonly abundant on the subtidal bottom. Most live in the sediment and communicate with the overlying water through a siphon. Burrowing bivalves that are common in muddy sediment are the stout razor (*Tagelus* *plebeius*), jackknife clam (*Ensis minor*), and angelwing (*Crytopleura costata*). Other bivalves that occur in the shallow subtidal zone are the constricted macoma (*Macoma constricta*), dwarf surf clam (*Mulinia lateralis*), and southern quahog (*Mercenaria campechiensis*). The coot clam (*Mulinia lateralis*) is a prolific member of the mud bottom community and serves as an important food source for diving ducks and shorebirds.

Gastropods that may live on shallow subtidal bottom are the predatory whelks *Busycon spiratum* and *Busycon contrarium.* The bubble shell (*Bulla striata*), virgin nerite (*Neritina virginea*), and mud snail (*Nassarius vibex*) are also found on shallow mud bottoms.

The most common large invertebrates typically present on the subtidal bottom are adult blue crabs (*Callinectes sapidus*) and penaeid shrimp (Powers, 1977). Blue crabs are good swimmers and are highly mobile, but will burrow into soft mud when shelter is not available. They are omnivorous scavengers that selectively feed on organic particles and soft-bodied invertebrates (Odum and Heald, 1972; Hamilton, 1976). Adult white shrimp (*Litopenaeus setiferus*) and brown shrimp (*Farfantepenaeus aztecus*) can be seasonally abundant on the subtidal bottom. They are omnivorous scavengers and grazers that feed on algae and organic detritus that accumulate as a flocculent in upper centimeter of sediment.

14.2.8.3.2 Analytical Chemistry Results

Table 9 (Summary of Results of Intracoastal Waterway Sediment) provides a summary of the Intracoastal Waterway sediment data used in the original gradient determination (i.e., for the Final BERA Work Plan & SAP) and the Intracoastal Waterway sediment analytical results generated from the BERA sampling. Table 9 also compares the TCEQ's marine sediment benchmarks and marine surface water benchmarks (TCEQ, 2006) to the 2010 BERA bulk sediment and pore-water data, respectively. Analytical results from the 2010 BERA sampling of Intracoastal Waterway sediment and associated reference sediment are presented in Figures 5 (Potential Source Areas) and 6 (EM Survey Transects and Data), respectively.

In general, the 2010 analytical results for Intracoastal Waterway sediments were lower than the analytical results from the RI data collected in 2008. There were no exceedances of the marine surface water benchmarks in sediment pore water. The only exceedances of sediment benchmarks were in sample EIWSED02 (for 4,4'-DDT, acenaphthene, and fluorene). As shown on Table 9, concentration gradients were identified for the majority of Site COPECs.

14.2.8.3.3 Toxicity Results

Table 9 includes a summary of the Intracoastal Waterway sediment toxicity testing (bioassay) results. For the polychaete, *Neanthes arenaceodentata* and the amphipod *Leptocheirus plumulosus,* there were no statistically significant differences between the five (5) Site samples and the two (2) reference samples for the survival or growth endpoints. Insufficient offspring were produced for a statistical analysis of reproduction for the amphipod.

The results of the toxicity study did not consistently correlate well with the results of the analytical chemistry.

14.2.8.4 Surface Water

Wetland and pond surface waters were evaluated through the collection and analysis of three (3) samples from the Site as shown on Figure 7 (Intracoastal Waterway RI Background Sample Locations). Surface water was not available at reference location EWSW02 (Figure 7 – Intracoastal Waterway RI Background Sample Locations). In general, surface water in the wetland area was not consistently present, and when present becomes highly saline as it rapidly evaporates. Surface water salinities measured by Benchmark Ecological Services, Inc. for EWSW01, EWSW03, and EWSW04 were 43‰, 27‰, and 42‰, respectively (Table 2 – Field Sampling Parameters – Water). These salinities were consistent with salinities measured in the laboratory by PBS&J Environmental Toxicology Laboratory (approximately 40‰, 30%, and 39‰ [as received] for EWSW01, EWSW03, and EWSW04, respectively). The COPECs for the surface water samples were location-specific. For EWSW01, the COPECs consisted of total acrolein and dissolved copper. The COPEC for EWSW03 was dissolved copper, and the COPEC for EWSW04 was dissolved silver. The original risk question that addressed the abundance, diversity, productivity and function of the fish community is not applicable because of the harsh conditions and intermittent presence of the surface water in a salt panne. However, the 48 hour toxicity tests using the brine shrimp as a test species addresses any potential toxicity to water column invertebrates that may inhabit the intermittent ponds.

14.2.8.4.1 Ecological Setting

As discussed in Section 1.3, the wetlands area is indicative of marsh flats, which contain shallow pools and salt pannes. A salt panne is periodically flooded by tidal events that bring fresh sea-borne nutrients, small fish, and invertebrates. When these shallow pools evaporate, salty brine remains. These areas in the wetlands often dry out completely, creating even harsher conditions. When the seawater evaporates, the salts remain and accumulate over many tidal cycles. The difficult environs of the salt panne usually have soils that are frequently waterlogged, making them devoid of oxygen. The high salt concentrations, waterlogged soils, and warm waters associated with salt pannes mean that not many plants can survive and the biological diversity is low. The surface water samples were taken from these shallow pools with elevated salinity.

14.2.8.4.2 Analytical Chemistry Results

Table 10 (Summary of Results for Wetland Surface Water) provides a summary of the wetland surface water results considered in the original gradient determination (i.e., for the Final BERA Work Plan & SAP) and the wetland surface water analytical results generated from the BERA sampling. Analytical results from the 2010 sampling of wetland surface water are also presented in Figure 7 (Intracoastal Waterway RI Background Sample Locations). The reference location EWSW02 was dry and could not be sampled for surface water. Because these pools are intermittent, acute surface water criteria (TCEQ, 2005) were used for comparison. There were no exceedances of surface water acute criteria in any of the samples.

14.2.8.4.3 Toxicity Results

There is considerable uncertainty with the surface water toxicity test using the test species *Artmeia*. The test was run three times for a duration of 96 hours; however, the results were not reproducible between the three tests for the three samples. Based on discussions during a meeting on December 1, 2010 with GRG, their consultants, TCEQ and EPA, it was decided that the toxicity testing would be presented based on the results at 48 hours.

EWSW-01 showed acceptable laboratory control survival for tests 1 (100%) and 3 (90%) at 48 hours with no indication of toxicity from the Site surface water at any dilution (survival ranged from 80% - 100%).

EWSW03 showed acceptable laboratory control for test 1 (100%) and test 3 (94%) at 48 hours with no indication of toxicity from the Site surface water at any dilution (survival ranged from 98% - 100%) in test 1, but low survival in test 3 in all of the test dilution (0% to 70%). It is unknown why the outcomes of the two tests were inconsistent.

EWSW04 showed acceptable laboratory control for test 1 (99%), but only 86% for test 3 at 48 hours. There was no indication of toxicity from the Site surface water at any dilution (survival ranged from 98% - 100%) in test 1. Survival in test 3 ranged from 82% to 98%.

14.2.9 Risk Characterization – Risk Estimation and Risk Description (Step 7)

The data collected to support the BERA were designed to address the ecological risk questions first presented in the Final BERA Work Plan & SAP:

1. Does exposure to COPECs in soil adversely affect the abundance, diversity, productivity, and function of the soil invertebrate community?

2. Does exposure to COPECs in bulk sediment and pore water adversely affect the abundance, diversity, productivity and function of the benthic invertebrate community?

3. Does exposure to COPECs in surface water adversely affect the abundance, diversity, productivity and function of the fish community?

Overall, the data met the data quality objectives identified in the Final BERA Work Plan & SAP, and are adequate for evaluation and risk characterization in the BERA as presented in the Final PSCR. However, the assumption presented in the Final BERA Work Plan & SAP that any impacts on toxicity would be solely due to Site COPECs proved to be incorrect. Similar inconsistent and modest toxicity was associated with soils/sediments from both the reference locations and the Site locations.

14.2.9.1 North Area Soils

The toxicity testing of *Neanthes arenaceodentata* over a 21-day exposure period showed no statistically significant differences between the North Area soil samples and the reference location soil samples. As summarized on Table 4 (Summary of Toxicity Testing for Soil and Sediment) and Table 5 (Summary of Results for North Area Soil), mean survival in the six (6) Site samples ranged from 76% to 96% and mean survival in the three (3) reference samples ranged from 60% to 92%. The growth data showed a similar relationship between the Site and reference samples. The results of the toxicity study did not always correlate well with the results of the analytical chemistry as compared to screening benchmarks.

The BERA concludes that there are no Site-related adverse effects when comparing the North Area samples to the reference samples and that exposure to COPECs in the North Area soil does not adversely affect the abundance, diversity, productivity and function of the sediment invertebrate community. Note that the original risk question was directed to soil invertebrates (earthworms), but through the BERA process it was determined that the habitat is not conducive to earthworms and is more applicable to saline tolerant sediment invertebrates.

14.2.9.2 Wetland Sediments

Toxicity testing of the wetland sediments was conducted using the 28-day whole-sediment tests for *Neanthes arenaceodentata* and *Leptocheirus plumulosus*. Table 4 (Summary of Toxicity Testing for Soil and Sediment) and Table 6 (Summary of Results for Wetland Sediment) summarize the toxicity test results for these samples. There were no statistically significant differences between the Site wetland sediment samples and the reference wetland sediment samples. The comparison of bulk sediment and sediment pore-water concentrations to screening benchmarks (Table 6) generally indicates a relatively low bioavailability and low potential for sediment toxicity. The SEM/AVS ratios presented in Table 8 (Summary of AVS, SEM and Organic Carbon-Normalized Excess SEM Data for Wetland Sediment) are all above 1.0, except for EWSED08 with an SEM/AVS ratio of 0.157, which indicates that the potential exists for metal toxicity since sufficient AVS to completely form insoluble metal sulfides is not present. However, sediment organic carbon can also bind the free metals and reduce their availability to aquatic organisms. The ratio of “excess” SEM to the fraction organic carbon content of sediment was below 130 micromoles per gram organic carbon ($\mu mol/g_{oc}$), the concentration predicted to be non-toxic by the EPA (2005), for six (6) of seven (7) Site samples. Also, the remaining Site sample (EWSED06) had an organic carbon-normalized excess SEM ratio of 168, which is at the low end of the range where the prediction of toxicity is uncertain (130 to 3,000 $\mu mol/g_{oc}$; EPA, 2005).

Because the results did not point to any single chemical stressor or physical parameter as the cause of any toxicity, further statistical analysis was conducted. Multiple linear regression (MLR), a form of multivariate statistical analysis, was selected to explore potential associations or dependencies between the various physical and chemical parameters (*i.e.*, the independent variables) and the toxicity test endpoints (*i.e.*, the dependent variables). "Associations," rather than "correlations." is the preferred term for the results of a multiple linear regression. An analysis of variance test that provides a correlation coefficient is a different statistical technique. Association does not prove causality, but causality cannot exist without association. The physical parameters evaluated in the MLR analysis included the sediment grain size percentages. The chemical parameters evaluated included total organic carbon (TOC), results of the AVS-SEM analysis, and the Site COPECs. The MLR analysis did not find any significant associations between PAHs and most metals for either toxicity test endpoint for either sediment test species.

Overall, the results of the MLR analysis indicate that some of the physical and chemical parameters, when considered individually or together in certain subsets, have statistically significant associations with the two toxicity test endpoints (*i.e.*, survival and growth). Zinc concentration indicated a statistically significant negative association (indicating a potential effect) and TOC indicated a statistically significant positive association with growth, but not percent survival, when regressed individually for *Leptocheirus plumulosus*. However, the adjusted correlation coefficients for these instances are low (*i.e.*, 50% or less) indicating weak correlations. Neither zinc nor TOC indicated statistically significant associations with growth (as measured by dry weight) or percent survival for *Neanthes arenaceodentata*. Therefore, only one of four possible outcomes indicated statistically significant associations.

A regression subset with statistically significant associations to survival for *Neanthes arenaceodentata* included TOC (positive) and percent medium gravel (positive). Similarly, the subset of TOC (positive), copper SEM concentration (negative), lead SEM concentration (positive), nickel SEM concentration (negative), and the sum of SEM metals' concentrations divided by the AVS concentration (negative) indicated statistically significant associations to dry weight for *Leptocheirus plumulosus*. A regression subset with statistically significant associations to survival for *Neanthes arenaceodentata* included percent clay (negative), percent fine gravel (negative), percent coarse sand (positive), percent fine sand (negative), and percent medium sand (negative).

These conclusions are somewhat confounded by the fact that no parameter's individual statistically significant association is ever true for both endpoints for the same organism or both organisms. These results may be related to the small number of dependent variables (*i.e.*, nine values per toxicity test endpoint) that creates a weakness of the MLR analysis.

The risk characterization results conclude that mortality and decreased growth of surviving organisms observed in the wetland sediment toxicity tests cannot be attributed to any one physical and/or chemical parameter. Considering the results as a whole, it is possible that a combination of parameters, such as TOC, certain sediment grain sizes, and contaminants (either inorganic or anthropogenically organic) may have influenced the pattern and degree of mortality of *Leptocheirus plumulosus* across all site and reference location wetland sediment samples.
Ultimately, the BERA concludes that there are no Site-related adverse effects when comparing the Site wetland area samples to the reference wetland sediment samples, and that exposure to COPECs in bulk sediment and pore-water does not adversely affect the abundance, diversity, productivity and function of the benthic invertebrate community.

14.2.9.3 Intracoastal Waterway Sediments

Toxicity testing of the Intracoastal Waterway sediment was conducted using the 28-day whole-sediment tests for *Neanthes arenaceodentata* and *Leptocheirus plumulosus*. Table 4 (Summary of Toxicity Testing for Soil and Sediment) and Table 9 (Summary of Results of Intracoastal Waterway Sediment) summarize the toxicity test results for these samples. There were no statistically significant differences between the Site Intracoastal Waterway sediment samples and the reference location Intracoastal Waterway samples. The comparison of bulk sediment and sediment pore water concentrations to screening benchmarks (Table 9) indicates a low potential for sediment toxicity.

The BERA concludes that there are no Site-related adverse effects when comparing the Site Intracoastal Waterway samples to the reference Intracoastal Waterway samples and that exposure to COPECs in bulk sediment and pore-water does not adversely affect the abundance, diversity, productivity and function of the benthic invertebrate community.

14.2.9.4 Surface Water

Only three of the four scheduled surface water samples from the wetland area were collected, and, as discussed in Section 1.3, the wetland area sampled can be categorized as a salt panne, with limited ecological resources. There were no exceedances of the surface water acute criteria for the COPECs, acrolein, copper, or silver (Table10 – Summary of Results for Wetland Surface Water) and the toxicity tests were no acutely toxic at a 48-hour test duration. The original risk question that addressed the abundance, diversity, productivity and function of the fish community is not applicable because of the harsh conditions and intermittent nature of the surface water in a salt panne; however, the 48 hour toxicity tests using the brine shrimp as a test species indicates a low potential for toxicity from exposure to surface water.

14.2.10 Uncertainty Analyses (Step 7 Continued)

Uncertainties are associated with each step in the BERA process, including problem formulation, ecological effects evaluation, exposure estimation, and risk characterization. According to the EPA (EPA 1997), "Uncertainty should be distinguished from variability, which arises from true heterogeneity or variation in characteristics of the environment and receptors." The interpretation of the BERA results are aided by a recognition and understanding of the source and nature of the known set of uncertainties that can influence the risk characterization results.

14.2.10.1 Uncertainties in Problem Formulation

Potential uncertainties associated with the problem formulation phase of the BERA are related to the identification of COPECs, contaminant fate and transport, and exposure pathways.

14.2.10.1.1 COPEC Selection

The BERA COPECs were identified using data obtained from the RI and presented in the Nature and Extent Data Report. These COPECs and others were identified as those with a potential to cause adverse effects as described in the Final SLERA. Elimination of certain COPECs during the SLERA streamlined the focus of the BERA to the COPECs that required additional investigation. Uncertainty may be associated with the environmental sampling for the RI and the BERA. Uncertainty may also be associated with the laboratory analysis of the Site samples, but there are a number of quality control and quality assurance measures that minimize errors and uncertainty.

It is believed that uncertainty associated with COPEC selection for the BERA is minimal since: 1) the SLERA process is, by design, conservative to avoid underestimating potential risk by inadvertently eliminating any COPECs, and 2) COPECs evaluated in the BERA were the more toxic (relatively) and prevalent compounds (both frequency and concentration) at the Site. Furthermore, if the presence of a chemical were responsible for decreased survivorship and growth, a statistical difference would have been more apparent between Site and reference samples, unless of course the compound(s) was present at both Site and reference sampling locations at similar concentrations.

14.2.10.1.2 COPEC Gradient

The 2010 sampling locations were chosen based upon the RI data obtained between 2006 and 2008. Between the RI sampling in 2006-2008 and the BERA sampling in 2010, there has been periodic flooding, in addition to the landfall of Hurricane Ike in September 2008. The potential impacts of these events on COPEC concentrations is unknown. However, the COPEC concentrations in BERA samples were generally less than COPEC concentrations in RI samples. If COPEC concentrations across the Site uniformly decreased because of flooding events, then the BERA sample locations based on RI data are equally representative of Site conditions, as if the locations had been randomly chosen. There is potential uncertainty in the true representativeness of the BERA COPEC concentrations, but it is considered to be minimal. The COPEC concentrations gradients are shown on Tables 5 (Summary of Results for North Area Soil), 6 (Summary of Results for Wetland Sediment), and 9 (Summary of Results of Intracoastal Waterway Sediment). The COPECs are adequately represented as being present at high, medium and low concentrations in relation to one another, i.e., a high concentration is the highest of the detected concentrations, but may not be considered high when compared to a benchmark. The presence of the concentration gradients meets the study objectives and there is little uncertainty associated with the presence of the concentration gradients for the COPECs.

14.2.10.1.3 Reference Sample Location Selection

Sediment reference locations were chosen as part of the initial investigation prior to the initiation of the ecological risk assessment activities. The soil reference area was selected during the RI field work. As recommended by EPA guidance (EPA, 2002), the ideal background reference areas should have the same physical, chemical, geological, and biological characteristics as the site being investigated, but without being affected by activities on the site. The reference areas were purposefully chosen out of the area of Site influence, but in areas that were grossly similar to the Site. There were no visible signs of disturbance, impact, or debris at any of the reference areas.

The reference locations are in the proximity of the Site where they are similarly influenced by storm surges and rain events, but are not so close in proximity to be influenced by site activities, as evidenced by data collected during the RI. The reference locations for the wetland sediment, North Area soils, and Intracoastal Waterway are considered appropriate and valid as an "ideal" background reference area as demonstrated by the low detections of chemicals, and similar physical and chemical characteristics as described above. As such, there is little uncertainty associated with using the reference samples for comparison to Site samples in the BERA.

14.2.10.2 Uncertainties in Exposure Analysis and Ecological Effects Evaluation

This section discusses the uncertainties in the exposure analysis and ecological effects evaluation phases of the BERA. Exposure can be expressed as the co-occurrence or contact of the stressor with the ecological components, both in time and space (EPA 1998). Uncertainties in the exposure analysis phase are centered on the quantification of the magnitude and patterns of exposure as they relate to the risk questions developed in the problem formulation phase. For this BERA, site-specific exposure response information was obtained by evaluating measurements of direct toxicity by multiple lines of evidence. The potential for confounding stressors that might influence the exposure response in the toxicity tests are discussed in this section.

14.2.10.2.1 Bioavailability

The uncertainty of the amount of the COPEC that is bioavailable to the ecological receptors is minimized in this BERA through the use of the whole sediment toxicity testing. The placement of the test organisms into the sediment creates an exposure potential that mimics the environment. Additionally, the sampling of pore water presents an additional line of evidence for bioavailability potential. When the Site pore water concentrations are compared to chronic surface water criteria, there were a few exceedances (*e.g.*, endrin aldehyde in the pore water from the wetland sediment); however, these exceedance do not correlate with toxicity especially when considering the similar results from the Intracoastal Waterway toxicity tests with no exceedances of marine surface water criteria compared to the pore water. This indicates that the bioavailable fraction of the chemicals is not a unique or significant contributor to toxicity in the Site or reference locations from either the Intracoastal Waterway or the wetlands sediments.

14.2.10.2.2 Synergistic or Antagonistic Effects of Constituents

Some constituents will vary in toxicity depending on the presence of other constituents, either by increasing absorption, uptake or toxicity (synergistic) or by decreasing absorption, uptake, or toxicity (antagonistic). The relationships between constituents are poorly understood, except for the select few that have been studied. In addition to constituent interactions, other environmental factors (total organic carbon, sulfide, pH, conductivity, etc.) can either increase or decrease the absorption, uptake, or toxicity of a constituent. The magnitude of these uncertainties is unknown for most constituents.

14.2.10.2.3 Naturally Occurring Organisms

The possibility that naturally-occurring benthic invertebrates might have influenced the test organisms through predation or competition for food is unlikely. Records from the PBS&J Environmental Toxicology Laboratory document that no invertebrates other than the test organisms were observed in the samples after test termination. Additionally, all of the samples were press-sieved (thereby likely eliminating predators) except for the heavy clay North Area soils that were hydrated for the 21-day polychaete test.

14.2.10.2.4 Laboratory Control Organisms

The uncertainties associated with the performance of the laboratory controls are minimal. All of the laboratory controls showed acceptable survival and growth. The average survival of *Neanthes arenaceodentata* in the controls ranged from 96% to 100%, whereas the average survival of *Leptocheirus plumulosus* in the controls was 81.5%. These results indicate that *Leptocheirus plumulosus* was more sensitive than *Neanthes arenaceodentata* to test conditions even in an optimal control medium.

14.2.10.2.5 Test Species

Two species were ultimately used in the sediment and soil toxicity testing (*Leptocheirus plumulosus* and *Neanthes arenaceodentata*) and one species was chosen for the surface water testing (*Artemia salina*). The choice of a test organism has a major influence on the relevance, success and interpretation of a test. Ideally, a test organism for use in tests should have: 1) a toxicological database demonstrating relative sensitivity to a range of contaminants of interest; 2) be in direct contact with the medium of interest; 3) be readily available from culture; 4) be easily maintained in the laboratory; 5) have a broad geographical distribution, be indigenous to the site being evaluated, or have a niche similar to organisms of concern (e.g. similar feeding guild or behavior to the indigenous organisms); 6) be tolerant of a broad range of physico-chemical characteristics (*e.g.*, grain size); and 7) be compatible with exposure methods and endpoints.

Amphipods like *Leptocheirus plumulosus* have been used extensively to test the toxicity of marine, estuarine and freshwater sediments. *Leptocheirus plumulosus* is an infaunal amphipod intimately associated with sediment, due to its burrowing and sediment ingesting nature. *Leptocheirus plumulosus* is found in both oligohaline (0.5-5 ‰) and mesohaline (5-18 ‰) regions of estuaries on the East Coast of the U.S and is tolerant to a wide range of sediment grain size distribution (EPA, 2001). There is uncertainty with using *Leptocheirus plumulosus* in the toxicity testing at the Site because it is not native to the area and generally prefers a less saline environment. The salinities from the Site ranged from 27 to 43 ‰. In general, the amphipod *Leptocheirus plumulosus* did not perform as well in the reference samples or laboratory control samples as the polychaete worm *Neanthes arenaceodentata*. The mean survival for *Leptocheirus plumulosus* in the laboratory controls was 81.5%, whereas the mean survival for *Neanthes arenaceodentata* in the laboratory controls was 100% and 96%. These results may indicate that *Leptocheirus plumulosus* is a more sensitive test organism than *Neanthes arenaceodentata*.

As noted in the field notes during the BERA sampling, *Neanthes sp*. were noted as present in the Intracoastal Waterway sediments during field collection, indicating that this genus is indigenous to the area. *Neanthes arenaceodentata* has been documented as a reliable test organism, especially for the sublethal effect of growth in marine sediment bioassays (Moore and Dillon 1993). Toxicity tests using *Neanthes arenaceodentata* were conducted at two exposure durations: 28 days and 21 days. This test organism is recognized as being used in 10 day and 20 to 28 days tests (ASTM 2007). The use of *Neanthes arenaceodentata* as a test organism is associated with little uncertainty in the BERA.

As previously discussed, the BERA Work Plan & SAP proposed the use of mysid shrimp as the test species, but when the surface waters were received at the laboratory the measured salinities were elevated beyond a level appropriate for the mysid shrimp. *Artemia salina* has an extreme euryhaline character. Its tolerance to salinity ranges from brackish water to saturated brines (Vanhaecke et al. 1981) and therefore was a logical choice as an alternate test organism for the highly saline surface waters at the Site. The performance of *Artema salina* as a test organism proved to be uncertain. The performances of the three tests were not consistent or reproducible. The ultimate conclusions of the surface water assessment is that the concentrations of the COPECs in the surface water were all less than acute criteria and the validity of the test at a 48-hour exposure was relatively stable between test runs.

14.2.10.3 Uncertainties in Risk Characterization

Risk characterization is the final phase of the BERA and includes two major components: risk estimation and risk description. Risk estimation consists of integrating the exposure profiles with the exposure effects information and summarizing the associated uncertainties. The risk description provides information important for interpreting the risk results (EPA 1997).

14.2.10.3.1 Uncertainties in the Comparison of Site Samples to Reference Locations

Because the reference samples were selected to be as identical as possible to the Site samples (minus the presence of site-related constituents) in regards to ecosystems, physical setting, and water chemistry per the Final BERA Work Plan & SAP, comparing the reference locations to the site samples imparts minimal uncertainty when evaluating the toxicity testing results. The magnitude of the uncertainty and influence on the BERA risk management conclusions is, therefore, expected to be minimal. Reference locations were utilized in the BERA for the study areas and media. The purpose of the reference samples was to be able to distinguish toxicity effects that would occur without the presence of the Site COPECs as defined by the SLERA. All of the results for the analytical chemistry and toxicity endpoints in Site samples should be considered in relation to the results from the reference samples. Both natural processes and anthropogenic processes could result in the presence of various stressors not associated with the Site:

- Natural processes could include deposition of naturally-occurring metallic minerals in sediments (e.g., silicon, calcium, sodium, potassium, phosphorus, carbonates, or sulfates); and

- Anthropogenic processes include deposition of chemicals from internal combustion engine exhaust, dredge spoil, mosquito spraying, highway runoff, and flood events. Marine engines have limited emissions controls for air emissions and no controls for particulate matter (EPA, 2010). Their emissions are therefore similar to what would be found on a busy highway.

14.2.10.3.2 Correlation of Toxicity Results with Other Factors

The results of the toxicity studies are not always well correlated to the results of the analytical chemistry when compared to benchmarks. For example, while reference concentrations of barium and zinc are elevated in soil sample NAS07, the mean survival of *Neanthes arenaceodentata* in that sample was high (92%). Contrastingly, reference concentrations of all metal COPECs are below the TCEQ's soil benchmarks for soil sample NAS09, yet this sample evidenced the highest toxicity (60% mean survival). This lack of correlation is not surprising given the many variables associated with site-specific toxicity testing when compared with benchmark values, which are derived using various methods and data sets.

14.2.10.3.3 Uncertainties with Artemia Testing

The surface water toxicity tests were run at a 96-hour duration, but there is uncertainty with the application of the 96-hour time frame for the evaluation of *Artemia salina* (brine shrimp). Test methods using *Artemia* are for 24 to 48 hour exposures (SPE, 1978). The exposure period of 24 hours is usually associated with the testing of freshly hatched individuals (nauplii). For the surface water toxicity testing completed for the Site, control failure did not occur at 24 hours (for all 3 test runs) or at 48 hours (from test runs 1 and 3 for samples EWSW01 and EWSW03). Sample EWSW04 in test 3 had a 86% survival for the control at 48 hours, but survival of *Artemia* in the Site surface water ranged from 82% to 98%. The 100% surface water samples (i.e., undiluted) for EWSW-01 and EWSW-04 exhibited survival rates of 97% and 99% in the first test, respectively, and 80% and 96% in the third test, respectively, after 48-hours, indicating consistency in the tests. Conversely, the 100% surface water sample (undiluted) for EWSW-03 exhibited survival rates of 100% and 0% in the first and third tests. The inconsistencies in the test results are likely due to the unreliability of *Artemia* as a test organism for tests of greater than 48 hours duration.

14.2.10.3.4 Toxicity Testing Duration

Ten-day tests are designed to be acute exposure tests for higher concentrations of toxic chemical compounds. Twenty-eight day tests are designed to be chronic exposure tests for lower concentrations of toxic chemical compounds to detect sublethal effects. The chronic exposure tests were selected as being the best measure of site conditions and potential toxicity from sediment samples for the Site.

If the conclusion is that the site COPECs are not the cause of mortality and decreased dry weight in the 28-day tests, then it follows that the COPECs would not be responsible for any observed adverse effects related to the COPECs in a proposed 10-day test. Sublethal and lethal effects caused by physical parameters (*i.e.*, sediment composition) of the sediment samples would likely be less evident in the shorter test. Adverse effects, unless acute in nature, take time to become manifest and measurable, whether related to chemical presence or physical attributes (*e.g.*, sediment grain size composition) in the organism's environment. The longer the bioassay test, the more exposure, and the more time there is for the adverse effect, be it slowed growth, delayed reproduction, or early death, to appear and be measured. Thus, the likely outcome of a shorter-duration test would be higher survival percentages and lower dry weight values (due to the shorter exposure time and lessened opportunity to feed and grow) among the replicates for both site samples and reference location samples.

Various studies were found in the literature to support the notion that variability (*i.e.*, uncertainty) in toxicity testing results may be greater for chronic exposures, but toxic effects are likely to become more evident. In one study with a different amphipod species (Nipper et al. 1999), short-term survival was not affected by large variations in sediment grain size but was correlated to growth in the 28-day exposure. Additionally, survival was much lower in the longer-term study, even for the uncontaminated reference site and the least contaminated site. The results for these two sites also evidenced greater variability in the 28-day study as opposed to the 10-day study. Growth was not measured in the 10-day exposure tests, nor was reburial measured in the 28-day tests.

An EPA guidance document (EPA 2001) on the method for chronic toxicity testing of sediments using the same amphipod species notes several studies that evaluated the comparative sensitivity between the acute and chronic tests. DeWitt et al. (1992 and 1997) noted that the reproductive endpoint of the chronic test was more sensitive than the survival and growth endpoints of the acute and chronic tests. However, another study (McGee and Fisher 1999) found the sublethal endpoints to be less sensitive than the survival endpoint.

14.2.11 Risk Management (Step 8)

Risk management is a distinctly different process from risk assessment. The risk assessment establishes whether a risk is present and defines a range or magnitude of the risk (EPA 1997). For this BERA, the risk characterization determined that there is no difference in the toxicity observed in samples collected at the reference locations and the Site for sediment/soil exposure, and that there was no toxicity associated with surface water. Because of the lack of Site-related toxicity, development of ecologically-based remediation goals was not necessary.

14.2.12 Conclusions of the Ecological Risk Assessment

Toxicity testing of sediment was conducted using the 28-day whole-sediment tests for *Neanthes arenaceodentata* and *Leptocheirus plumulosus* using the wetland sediments and Intracoastal Waterway sediments. A 21-day whole sediment/soil toxicity test using *Neanthes arenaceodentata* was applied to the North Area soils. The bioassays for the surface water were conducted on brine shrimp (*Artemia salina*) and assessed at a 48-hour duration. Sample locations were chosen based on a concentration gradient of the chemicals of potential ecological concern (COPECs) identified in the SLERA.

The analysis of the toxicity and analytical data for all of the sediment areas showed that the most relevant comparison was of Site sample results to reference location samples results. This enables the comparison of results between Site samples and those reference samples that exhibit similar environmental conditions, but are not influenced by releases from the Site Ultimately, it was determined that there is no difference in the toxicity observed in samples collected at the reference locations and the Site for sediment/soil exposure and that there was no toxicity associated with surface water. Because of the lack of Site-related toxicity, development of ecologically-based remediation goals was not necessary.